



Lewis Research Center

Space Station Fluids and Combustion Facility



Chapter 6 - Operations Requirements Envelope

Chapter 6 - Operations Requirements Envelope

6. OPERATIONS REQUIREMENTS ENVELOPE

6.1 INTRODUCTION

The detail of technical requirements (Sections 4 and 5) might be considered the "skeleton" of requirements upon which the facility is built. If so, the facility's operating infrastructure (highlighted, in part, in Section 2) would be the "flesh and muscle" that make the facility work and the operational style of the facility team is, most certainly, the "personality or image" of the facility to the science community.

As noted in Section 3.5, the primary interactions of the facility team with each Principal Investigator (PI) occur during the "operational" phases of the experiment implementation process:

- **Experiment Development** (Section 6.2): development, test and verification, training for flight operations
- **Flight Operations** (Section 6.3): preparation for launch, real-time flight instrument operations (science operations)
- **Post-Flight Operations** (Section 6.4): post-flight distribution of science data

The purpose of this section is to identify key elements within these operational processes which directly involve the science team and will impact the quality of the experiment or the science throughput of the facility.

For clarity, the discussion is presented in terms of an overall process flow; however, this particular process is

not unique but is employed to identify key steps or controls which are highlighted as specific requirements or recommendations.

Due to the significant time and effort typically invested in operations activities, this aspect of the FCF must reflect efficient and helpful support to the science team. The goals stated in Section 3.2 will primarily be achieved by efficiencies in the processes discussed in the following sections.

The range of operations are discussed in the following sections (as displayed in the figure below).

Facing figure shows the major subsections of this section and their contents.



OPERATIONS REQUIREMENTS ENVELOPE

6.2 EXPERIMENT DEVELOPMENT

- Concept Design
- Experiment Development
- Instrument Verification

6.3 FLIGHT OPERATIONS

- Packaging/Launch Support
- Assembly/Integration
- Readiness Assessment
- Science Operations

6.4 POST FLIGHT OPERATIONS

- Hardware and Sample Return
- Data Reduction/Distribution

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6.2 EXPERIMENT DEVELOPMENT

The development of instrumentation to successfully implement investigator-specific science requirements will remain the dominant effort for each experiment.

Within the scope of a successful FCF, the potential exists for significant savings in cost and schedule. These benefits will arise, primarily, because the experiment hardware concepts will evolve within the context of "existing, verifiable measurement" capabilities rather than on the traditional "clean sheet of paper." This will enable a hands-on, experimental approach to early assembly and verification of performance of each PI's flight instrument. In particular, the facility approach should minimize the need for development of new capabilities for each flight experiment.

The following discussion describes the PI hardware development cycle in terms of three major "phases":

- 1) Concept Design (Section 6.2.1)
- 2) Development and Functional Verification (Section 6.2.2)
- 3) Flight Instrument Verification (Section 6.2.3)

A flow diagram of such a process is shown below and those tasks involving each PI are emphasized in the figure by a dark background highlight.

The process assumes availability of a finalized Science Requirements Document (as discussed in Section 3.5.1) and an appropriate set or "menu" of capabilities provided by the FCF (as either on-orbit capabilities or ready-to-fly hardware). The "menu" must initially accommodate the first few flight experiments and should continually grow through the life of the facility.

From the user perspective, a key aspect of this flow is the experimental validation/verification of functional performance within each phase. Concept verification must occur as early as possible. In the ideal case, adequate FCF hardware capabilities will already exist and straightforward early demonstration of each experiment will be possible. Final experimental verification of the measurement requirements will occur using the flight hardware (some of which may be on-orbit).

The convenience and quality of performance demonstrated within the experiment development process will be important factors to the investigation. The clarity with which constraints, such as safety containment, disposal of chemical waste, and integration/launch loads analysis are presented and (appropriately) handled is important to minimize distraction from the measurement science (i.e., the facility should strive to develop a system that minimizes the impact of these necessary, but repetitive, operational tasks on the science user).

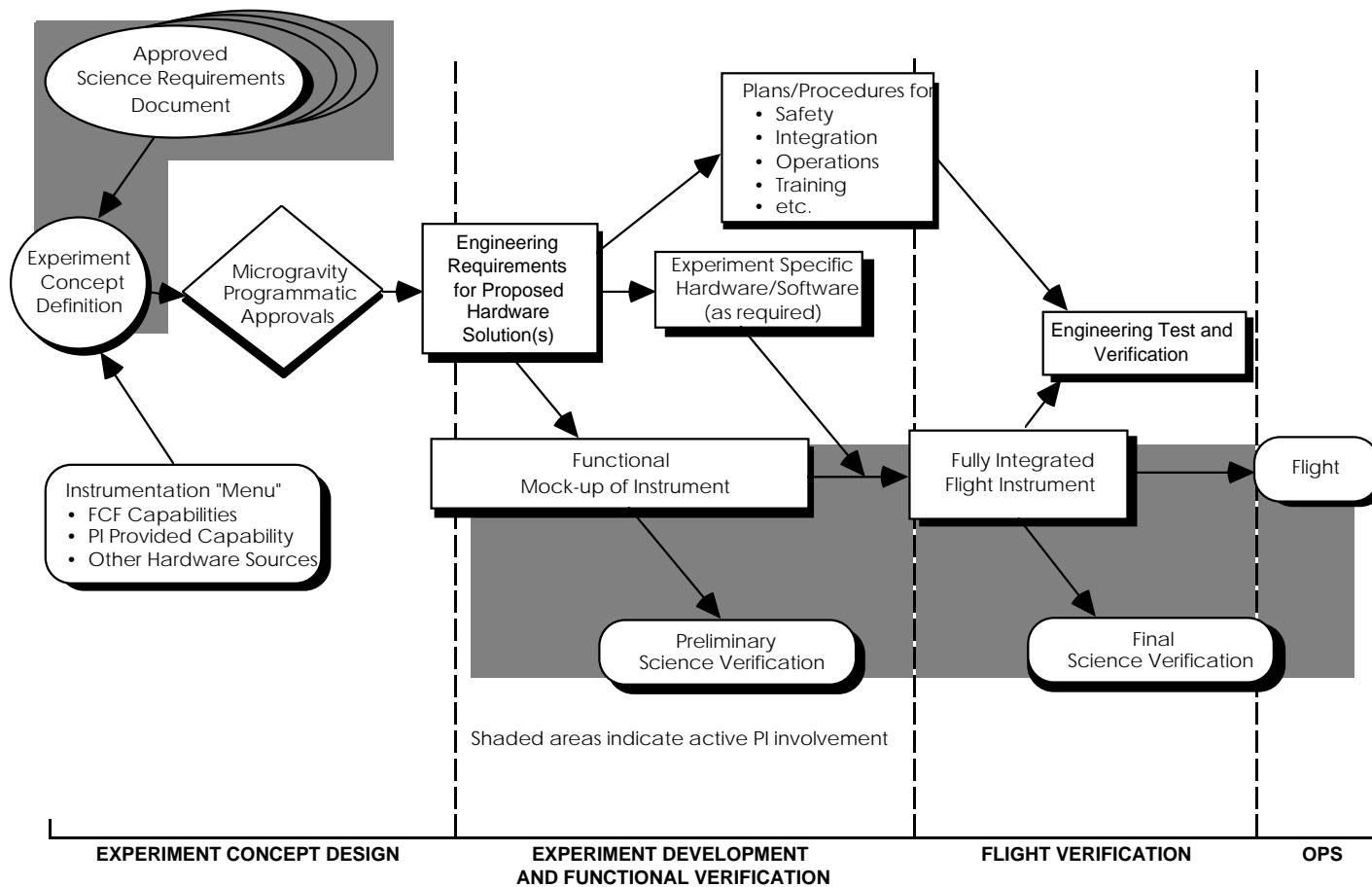
Facing figure diagrams an evolution of an experiment from Science Requirements to flight. Those tasks involving each investigator are emphasized in the figure by a dark background highlight



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EVOLUTION OF REQUIREMENTS TO FLIGHT HARDWARE



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6.2.1 EXPERIMENT CONCEPT DESIGN

The process leading to a design concept for each experiment could exhibit the most significant differences from current generation experiment development processes. Evolving experiments within the envelope of existing FCF instrumentation offers the greatest opportunity for meeting the goals for faster and cheaper experiment implementation.

To facilitate efficient designs optimally while incorporating facility capabilities the following are desirable:

- PI-specific science requirements should be based on experimental demonstrations (by the PI)
- science feasibility issues should be resolved prior to experiment concept definition
- science program management should be involved early in the evaluation of experiment concepts to expedite the flow of PI-specific science and to coordinate potential grouping of PI's having complementary science requirements

Experiment concepts might have two extremes:

- 1) An experiment fully-configurable from existing FCF elements: This would provide the ultimate return on FCF investment and require the minimum time and money.
- 2) An experiment so unique that custom instrumentation is required and the FCF would provide only a set of basic services, such as: power, cooling, and communications support.

The facility will be best utilized when well-defined PI requirements and informed perspectives of FCF capabilities

are brought together with an FCF integration team capable of quickly understanding the requirements and efficiently offering verifiable options for addressing them.

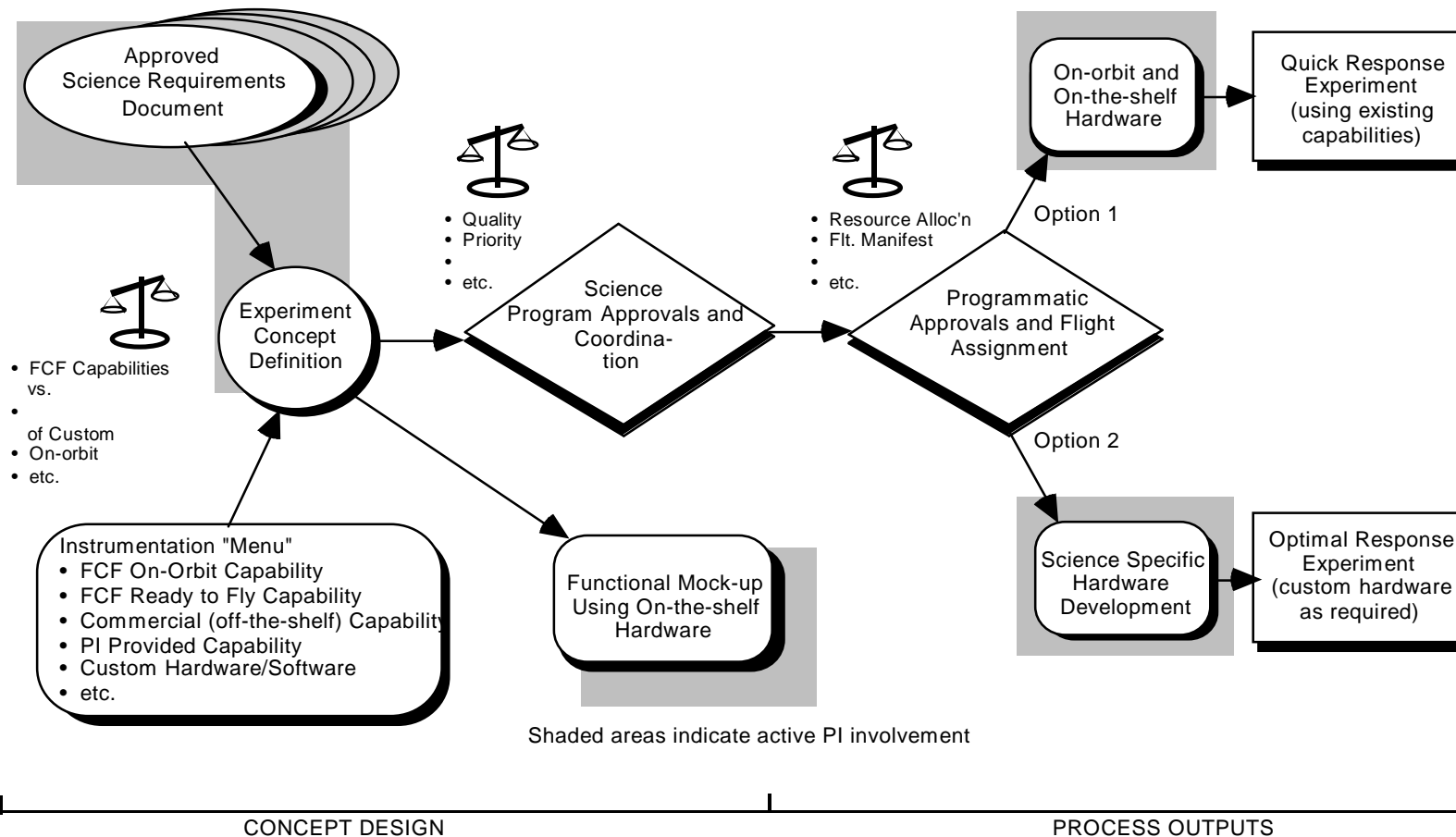
The design of the FCF shall strive to meet all experiment requirements; in addition, the FCF should, where a rational alternative is apparent, offer the best solution accessible within (predominantly) existing FCF capabilities and offering a cost-effective implementation of the experiment that addresses at least 80% of the PI's requirements, and meets facility cost and schedule goals.

(continued on Page 8)

Facing figure diagrams the flow of science requirements into concept design negotiations to facilitate utilization of facility hardware. Decision points reflect an assumed separation of oversight decisions: science program selection of viable approach followed by Space Station programmatic identification of flight opportunity.



EXPERIMENT CONCEPT DESIGN



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6.2.1 EXPERIMENT CONCEPT DESIGN (cont.)

Requirements:

Req. 01

The FCF shall provide plans for screening experiment requirements during Phase A/B (of experiment evolution), educating PIs on capabilities of FCF, reporting assessment of requirements (from FCF perspective) at requirements reviews, and accepting, ideally, only those requirements which have been experimentally verified and demonstrated to be feasible for flight.

Req. 02

The FCF shall provide staff members having appropriate expertise in disciplines necessary to functionally demonstrate and verify all measurement capabilities provided by the FCF. (This expertise is deemed necessary to efficiently negotiate the experiment design concept with each PI and to justify the need and requirements for additional, custom hardware capabilities.) Individual experiment models shall be employed at the earliest opportunity for each experiment.

Req. 03

The FCF engineering assessment and proposed hardware solution for approved PI science requirements shall be documented in a form easily disseminated and understood and employed in: (a) engineering response at each review of requirements; (b) planning of cost and schedule for implementing the subject experiment on the FCF; and (c) as part of the informational material provided to the science community (particularly potential flight participants).



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6.2.2 DEVELOPMENT AND FUNCTIONAL VERIFICATION

Development of experiment hardware within the facility environment has great potential for efficiencies in time and cost (as noted in Section 6.2.1). To facilitate optimal flow of concept to hardware, it is desirable to:

- focus on early experimental demonstration/verification of primary measurement and control systems (this should be achievable with facility hardware and personnel)
- utilize PI-generated hardware and software when possible to expedite demonstrations and provide potential flight designs
- involve the PI science team actively in all development tests and demonstrations to achieve early acceptance of hardware performance and to utilize existing analytical expertise
- have PI science team "on-line" during test and verification to demonstrate standard software capabilities and provide early training in science operations

Requirements:

Req. 04

FCF shall provide plans which enable cost-effective utilization of hardware provided by PIs or common commercial providers.

Req. 05

FCF shall provide access by each PI to functional models of the experiment measurement system to enable early verification of functional requirements.

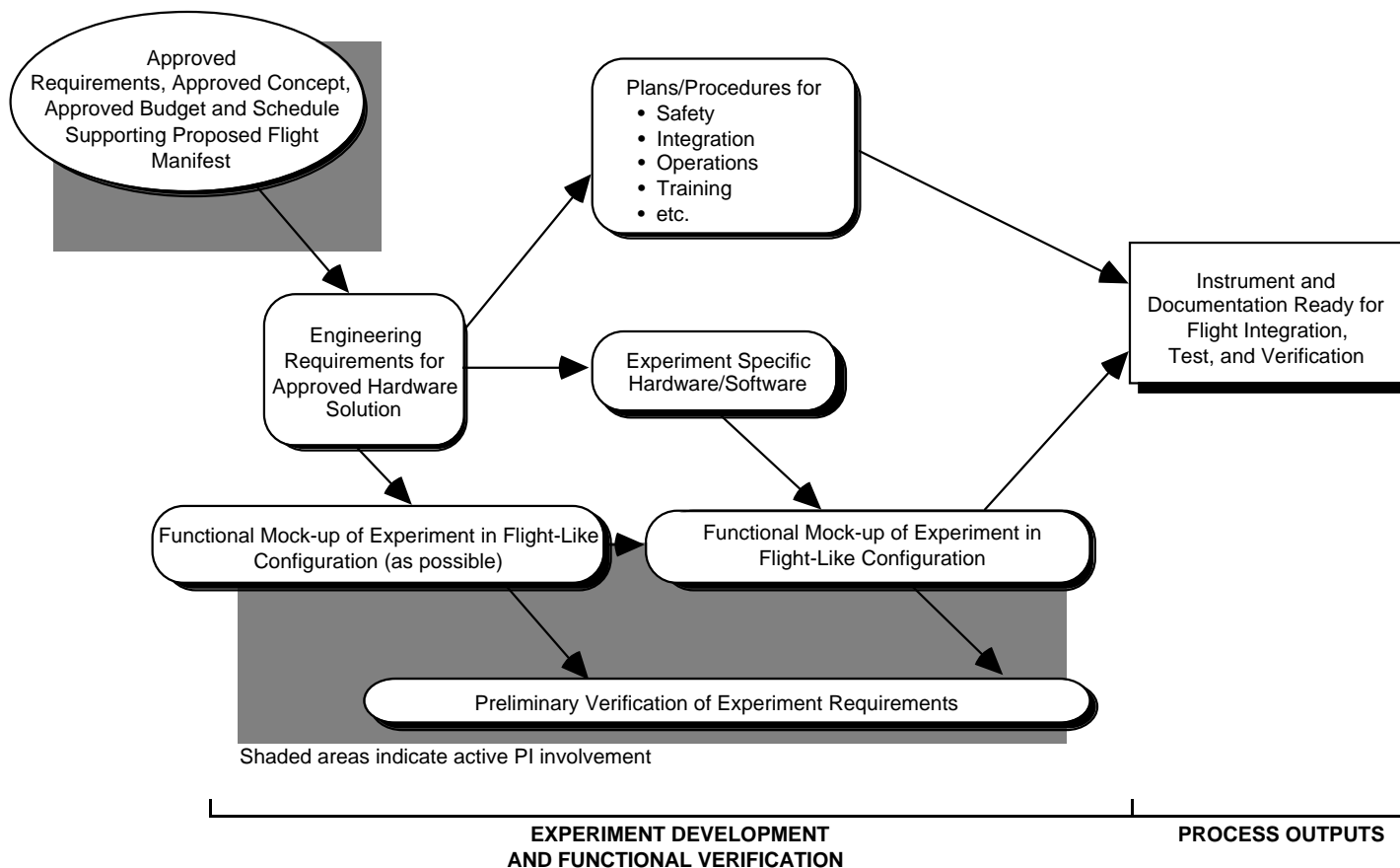
Req. 06

FCF shall provide access to flight-like communications capabilities during the development process to enable PI monitoring of development, test, and verification data, and to promote development of display and analysis software at the PI's site.

Facing figure highlights selected activities during development and functional verification process.



EXPERIMENT DEVELOPMENT AND FUNCTIONAL VERIFICATION



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6.2.3 FLIGHT INSTRUMENT VERIFICATION

In the tradition of flight programs, the experiment hardware will undergo a verification test program to ensure compliance with established science and engineering requirements. To meet the utilization goals, it is necessary for the FCF to provide the most efficient path to verification and acceptance.

To demonstrate that the facility reliably produces high quality measurement science, the FCF must provide a test process that appropriately verifies the key measurement functions by functional test or calibration. This process should include verification testing of the diagnostic or measurement instrumentation that resides on-orbit, as well as the freshly integrated hardware.

The technical credibility of each experiment depends upon clear and well-documented certification of performance. In particular, the PI should have access to the flight instrument (at least the ground equivalent) to conduct more than one end-to-end test of important elements of the mission test protocol.

The specifications of “standard” capabilities advertised by the FCF should reflect intelligent conservatism that permits continual and confident ability to demonstrate compliance on demand.

Requirements:

Req. 07

The FCF shall provide a process that efficiently qualifies and verifies experiment hardware for launch and flight operations, while minimizing impact to the investigator and maximizes instrument availability for science verification

and characterization prior to flight. The facility should provide for standardized approaches to meet safety and integration requirements that minimize time and effort (and resultant costs) involved in these activities.

Req. 08

The FCF shall provide a process for verifying science requirements that accommodates PI involvement in defining test criteria and procedures in order to minimize potential misunderstandings of test procedures and data interpretation. PI participation in functional verification testing and data reduction should be optimized.

Req. 09

The FCF shall schedule verification activities so that each experimenter has time to simulate more than one mission timeline sequence in the flight-like configuration.

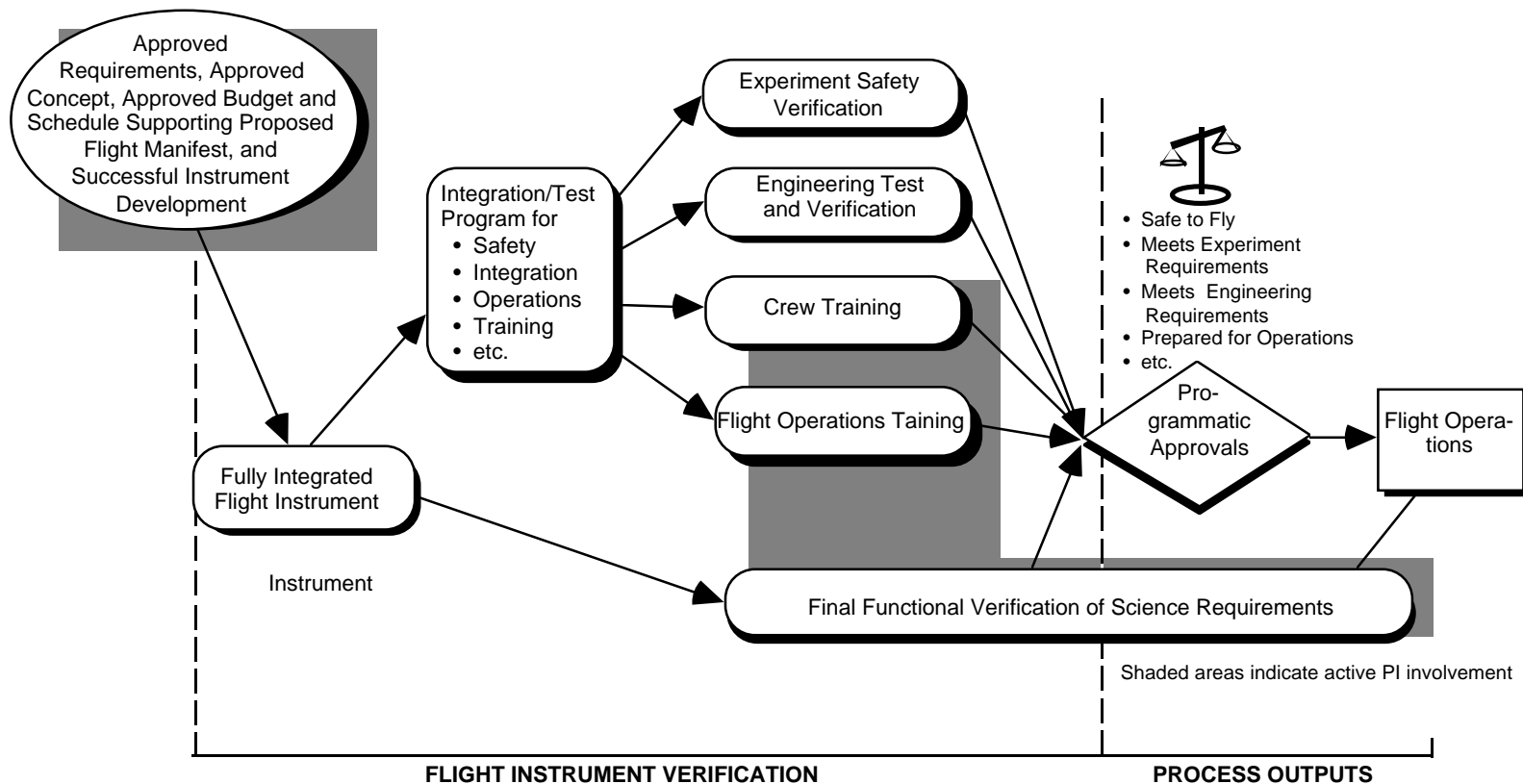
Req. 010

Functional performance of facility-provided measurement instrumentation that is integrated with science-specific hardware on-orbit shall be verified in situ or shall be traceable to certified reference standards. The FCF team shall recommend verification procedures for techniques that will be maintained on-orbit.

Facing figure diagrams important activities during the final verification phase.



FLIGHT INSTRUMENT VERIFICATION



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6.3 FLIGHT OPERATIONS

Flight operations include all activities occurring on the ground in preparation for and during performance of the flight experiment and, also, all activities occurring on-orbit during operation and execution of the experiment (science operations).

All "payload operations" which directly affect each PI are of interest to the science community; however, the science operations phase is the culmination of the experiment and must reflect science inputs. Most significantly, the style of flight operations chosen for the facility will determine the convenience and appeal of the facility as an accessible and useful "science laboratory" and, therefore, will affect levels of utilization of the facility.

The major elements of these operations are discussed herein and include:

- Ground support of flight operations will include the following:
 - integration of the experiment elements for launch
 - training of the crew for installation and operation of PI hardware and flight instrumentation
 - training of the science team and FCF team for operation of the instrument and conducting the experiment
 - provision and operation of science operations hardware and software
 - coordination of the science payload operations (communication and control)
 - distribution, storage, and analysis of science data
 - support of distributed operations centers (PI sites)

- On-orbit flight operations will include the following:
 - installation of PI-unique hardware into the facility
 - implementation of any setup/checkout operations (e.g., final verification of safety and measurement capabilities not tested on Earth)
 - science operations (including contingency operations for clean-up, repair, and work-arounds)
 - Removal, packing, and return of the instrument

On-orbit hardware installation and test activities are key to instrument performance and will enable optimum utilization. The clarity and simplicity of the physical interfaces and the versatility of the facility hardware concepts are key elements for successful implementation of this interface. However, most of the investigator's interaction with facility systems will be filtered by the software-driven interface.

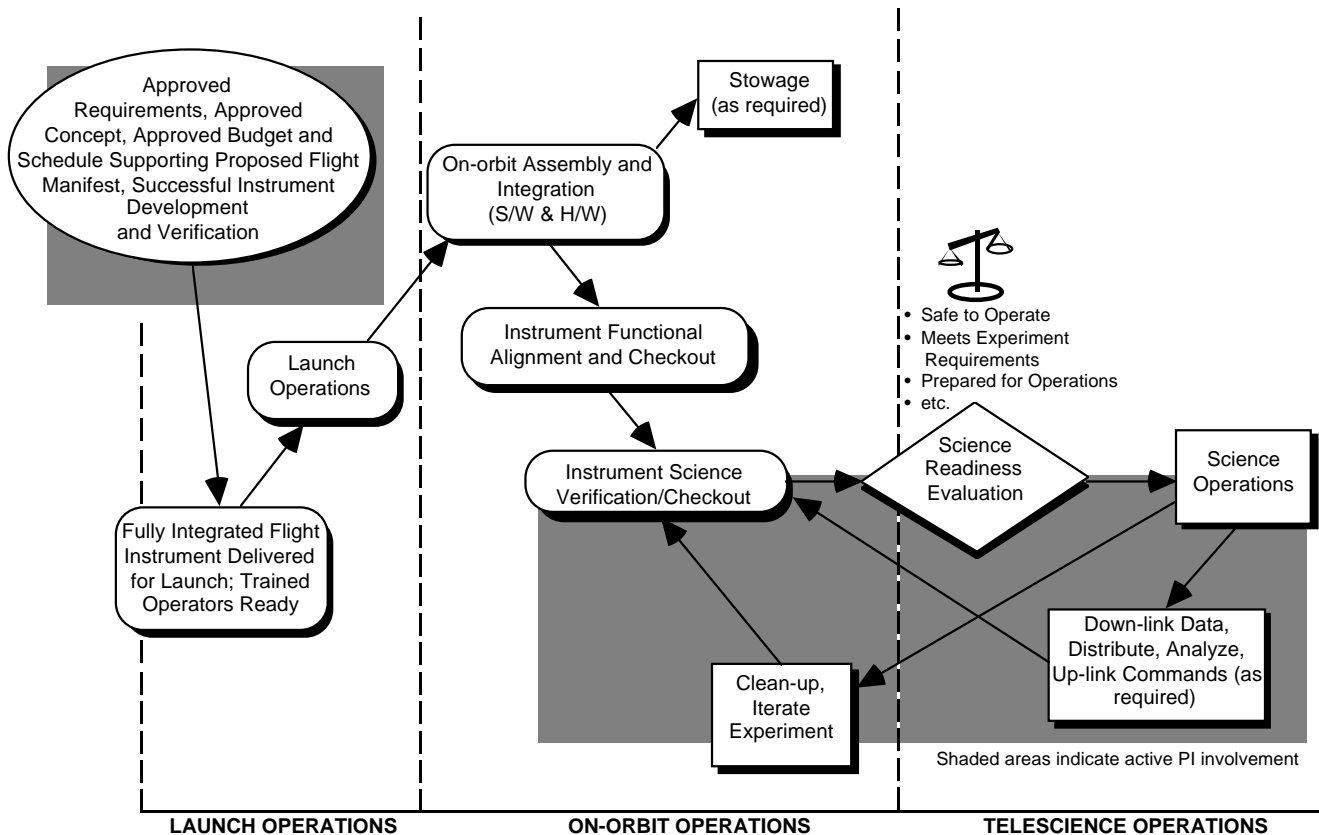
Facing figure displays selected highlights of flight operations.



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FLIGHT OPERATIONS



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6.3.1 PACKAGING/LAUNCH SUPPORT

Ideally, the flexibility and utility of the FCF should not be constrained by any operational aspect of the facility. This philosophy begins with access to orbit and the ability to conveniently and reliably launch and store all required experiment elements.

The requirements derived from this philosophy are not driven by specific science elements, but by the goals for high levels of utilization and low operating costs over the life of the facility. The science community will expect the facility to aggressively pursue all opportunities to increase access to launch capability (both mass and volume) and on-orbit stowage through innovative packaging and handling techniques.

Requirements:

Req. 011

The FCF shall provide packaging and handling concepts for launch and recovery that will accommodate all hardware sizes and configurations compatible with the FCF, while minimizing launch mass and volume.

Req. 012

The FCF shall provide packaging and handling concepts which minimize the time required for off-loading, sorting, and stowing facility hardware and supplies. This is essential to optimize crew time available for significant science functions.

Goal:

GO1

The FCF shall provide internal stowage for at least one fluids and one combustion experiment (experiment-specific hardware, expendables, etc.), facility spares and maintenance supplies, in addition to the two installed experiments.



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6.3.2 ON-ORBIT ASSEMBLY AND VERIFICATION

The hardware installation and test activities are key to credible instrument performance. The facility approach provides the new challenge of assuring high quality performance of equipment (e.g., cameras, optical subsystems, and light sources) that may have been stored on-orbit or maintained in use for extended periods. Experiments are expected to be performed within the advertised specifications provided by the on-orbit instrumentation. The FCF will also provide many science-critical functions (e.g., thermal and vibration monitoring and control).

To avoid extended periods of hands-on integration and test by the crew each time a new experiment is implemented, it is necessary to rely on autonomous or ground-controlled verification and tuning of alignment and detailed experiment configuration.

Requirements:

Req. 013

The FCF hardware and assembly concepts shall minimize demand for crew time to reserve more crew time for science operations.

Req. 014

The FCF shall provide on-orbit capabilities and/or ground-proven strategies for verifying calibration and performance of key measurement techniques.

Req. 015

The FCF shall provide monitoring of primary environmental parameters (temperature, acceleration, and vibration) within the science module racks.

Req. 016

The FCF shall provide video monitoring (standard video quality) of the assembly and service processes to enable real-time support by the ground support team and to provide a record of the on-orbit assembly operation. Similarly, a video monitor within the facility permitting display of instructions and/or supporting data from the ground operations team would greatly enhance efficiency of interactions during setup and crew operations.

Goal:

GO2

The FCF shall strive to achieve commonalty between fluids and combustion facilities to optimize interchangeability of optical, diagnostic, and electronic subsystems.

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6.3.3 SCIENCE READINESS ASSESSMENT AND COORDINATION

To assure that high levels of facility utilization can be maintained and that each investigator has a well-defined avenue for initiating or terminating science operations, it is necessary that the FCF provide a systematic process to coordinate the availability and judge the readiness of Space Station, FCF, and experiment systems and resources.

Requirements:

Req. 017

The FCF shall coordinate all on-orbit activities and assess readiness to proceed with science operations following the complex sequence of assembly and alignment activities envisioned that includes science participation. The FCF team shall prioritize alternate actions if plans must be modified (other experiments, alignment/test activities, maintenance, etc.). Each investigator must be a participant in the process by implementation of a working group (or equivalent). The importance of coordinating multiple users and ongoing facility maintenance activities should not be underestimated.

Req. 018

The FCF shall provide a process plan for resolving conflicts relating to utilization of facility resources when they are encountered (e.g., communication downlink, power, cooling, etc.). The process should encourage full utilization of the facility and optimal performance of approved science.

Req. 019

The FCF team shall provide near-real time reports of

thermal, vibration, and acceleration environments to assure readiness for science operations.



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6.3.4 SCIENCE OPERATIONS

The ultimate purpose for the FCF is to execute well-defined science experiments in the unique orbital environment and relay the measurement data to the Principal Investigator team. This science operations phase is typically the culmination of many years of ground-based research and many hours of preparation by the science team with a yield of a few, select data points.

The FCF contribution to this phase is, ideally, so carefully prepared and professionally implemented that it becomes nearly transparent to the science team. While the demands of coordinated flight development and engineering necessarily dominate the development and test phase, science must be fully served during science operations. Ideally, each PI should be offered the opportunity to interactively control an experiment on the Space Station that fully reflects established requirements and "feels" as though the science were being conducted in his/her own laboratory.

This section describes selected aspects of science operations and highlights specific facility capabilities which are expected by the science community. The topics included are:

- Instrument Operations (Section 6.3.4.1)
- Operations Center Capabilities (Section 6.3.4.2)
- Data Display and Analysis (Section 6.3.4.3)

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6.3.4.1 FACILITY SUPPORT OF EXPERIMENT OPERATIONS

The challenge to the FCF is to permit each science team to believe that they are in a position to truly “do science” rather than simply iterate a limited set of prior actions.

The highest praise this facility should expect from a science team is an acknowledgment that the science operations produced quality data “just as if the instrument were in the lab next door.”

Requirements:

Req. O20

The FCF shall provide maximum downlink of near real-time data (optimized for the active experiments). Where experiment-specific data streams exceed Space Station capabilities, the FCF shall provide alternate strategies to accommodate experiment control, store real-time data, and ultimately deliver all required data to the ground.

Req. O21

The FCF shall provide reliable capabilities for recording and protecting science data on-orbit. This shall include

- Adequate memory to record all required data from one run of each active experiment in a time tagged format permitting convenient recall
- Clear identification of data existing only on-orbit (i.e., to assure that no data is lost before downlink or erased without confirmed choice.

Goals:

GO3

The FCF shall provide an operating environment that "protects" both science and facility interests during all critical operations while permitting adequate flexibility to allow the science team enough "parameter space" to resolve real science questions and explore unforeseen phenomena.



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6.3.4.2 OPERATIONS CENTER CAPABILITIES

The FCF ground support system that provides command, control, data recording and display is part of a complex network of coordinated communications systems which link the scientist to a flight experiment in a rigorously controlled manner. The part of that system visible to the scientist is a finite set of software driven computer terminals located in an “operations center.” This interface is of utmost interest to each PI because it is the physical link to the experiment.

The primary functions of the operations center include

- controlled communication (for command and control of experiment and facility),
- coordination and control of facility functions,
- recording and distribution of experiment data, and
- display of experiment and ancillary data
- analysis and error monitoring of key experiment and facility data

The FCF goals for extended periods of operation and low cost implementation are best served by permitting the science teams to conduct science operations from their own base of operations. This leads to the desire for “distributed” science operations which appear ever more accessible in the context of modern digital communications links.

Requirements:

Req. 022

The FCF shall provide an operational capability that reliably verifies the quality of all data and commands transmitted to/from each experiment.

Req. 023

The FCF shall monitor essential Space Station, FCF, and experiment parameters to ascertain nominal performance of these systems, identify off-nominal conditions, and initiate malfunction procedures when required.

Req. 024:

The FCF shall provide reliable capability for recording and distributing all facility data (science, environment, “housekeeping,” etc.) to multiple (order 10) users in a minimum of 3 locations. The capability should be flexible in a manner that does not permit it to be slowed by one or more high density data stream (e.g., high resolution video).

Goal:

GO4

The FCF should strive to provide full communication and science data capabilities and occasionally command capabilities (when that makes sense) at user sites.

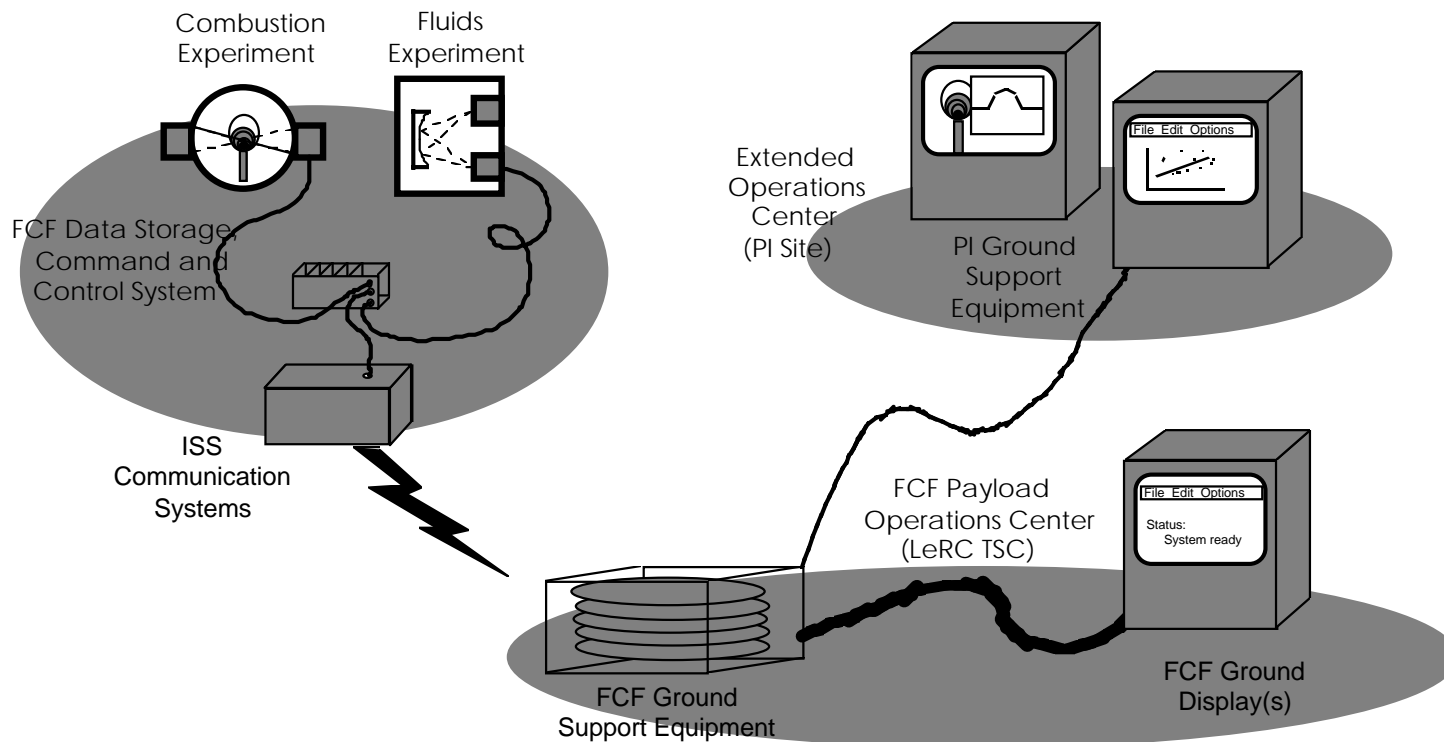
Facing figure shows the scope of the distributed data network for FCF.



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DATA ACQUISITION AND DISTRIBUTION NETWORK DURING FLIGHT OPERATIONS



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6.3.4.3 DATA DISPLAY AND ANALYSIS

Modern science and engineering instrumentation is increasingly data intensive. Accommodating useful display and analysis of very large data flows requires careful planning and capable facilities. It is expected that ALL down linked data from the FCF should be accessible on displays in near real-time. Most of the data will exist as time based serial streams.

The challenge of handling multiple video channels (often with very high resolution data) will be an ever increasing problem for FCF and, in particular, should be well planned at the outset. It may be impossible to transfer some large image files to extended locations in near real-time using the technology currently accessible. However, the user community expects the facility to implement upgradable subsystems which will accommodate new communication and display technologies as they evolve.

There will be several sources of data of interest to the science teams:

- primary experiment data (precision measurements, images, etc.)
- supporting instrument "housekeeping data" (local voltages, currents, temperatures, status, etc.)
- experiment environmental conditions (facility controlled or monitored temperatures and accelerations, etc.)
- FCF "housekeeping data" (currents, voltages, memory status, operational errors, etc.)
- Space Station ancillary data (maneuvers, crew actions, current attitude, etc.)

It is desired that each science team have access to all data affecting their experiment.

Requirements:

Req. 025

The FCF shall provide a capability to display standard serial data streams in tabular or graphical form. It is expected that "standard" analyses of graphical data (e.g., curve fitting, smoothing, differentiation, etc.) shall be available in menu -driven packages on the GSE. It is desired that such capability be compatible with typical laboratory and office computers for ease of implementation in user laboratories.

Req. 026

The FCF shall provide user access to all data called out in experiment-specific science requirements.

Req. 027

The FCF shall provide image display capabilities compatible with facility imaging technology. The FCF shall provide such displays to remote operation sites for flight operations if comparable displays are unavailable to the user.

Req. 028

The FCF shall provide science data streams in formats compatible with existing commercial standards to enable users to directly transfer data to laboratory analysis and display systems.



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6.4 POST-FLIGHT OPERATIONS

The culmination of a flight experiment occurs on-orbit for the brief, intense period of Science Operations. However, the real "work" of the science team occurs in the post flight period as data sets are retrieved and stored, data is analyzed, issues (with science or hardware) are identified, and follow-up experimentation occurs.

It is essential that the FCF support this phase of the activity efficiently to permit timely initiation of analysis and reporting of data by the PI and the science team. The timeliness and the quality of final data deliveries will clearly indicate when the facility controlled operations are complete.

It is also necessary that the FCF support the science team as required to verify experiment performance or repeat Earth-based measurements required to address questions raised by the flight experiment. This could require access to facility equipment (ground support equipment or functional equivalent of the flight experiment).

Requirements:

Req. O29

The FCF shall define a process for support of each PI during post flight operations to assure full compliance with data delivery requirements.

Desires:

DO1

The FCF shall support each PI with required hardware to address likely needs for post flight verification of science data and instrument performance, as feasible.

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6.4.1 HARDWARE AND SAMPLE RETURN

All data generated during the course of flight operations as physical samples (e.g., soot or gas samples) or in hard data formats (film, tapes, disks, etc.) must be made available to the science team for analysis and archiving.

The FCF should strive to return all User supplied (experiment specific) hardware following use.

Any PI-specific capabilities deemed useful as on-going facility capabilities should be identified and negotiated early during experiment evolution to identify any potential issues relating to proprietary or patent claims.

Requirements:

Req. O30:

The FCF shall provide for on-orbit stowage and safe return of chemical samples generated during on-orbit operations.

Req. O31:

The FCF shall provide for on-orbit stowage and ultimate return of all hard copy data generated on-orbit.

Desires:

DO2:

The FCF shall return (as possible) all experiment-specific equipment and samples utilized during operation of the experiment.



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6.4.2 DATA REDUCTION AND DISTRIBUTION

All data generated during the course of flight operations for each experiment should be made available to the science team for analysis and archiving. These data will include time stamped, digital data files including all measured parameters required by each PI and all pertinent images required by each PI. All samples and recorded data produced on-orbit will be unique and must be protected and delivered to the investigator. Ancillary data of value to the investigator (e.g., accelerometry records, facility “housekeeping” data (voltages, currents, outages, etc.) should be made available upon request.

The ongoing orbital presence of the facility and the cumulative history of environmental conditions and facility functional performance should evolve as a resource for facility users. The FCF should provide summary reports of nominal average environment within the facility and significant deviations from the norm during the course of each subject investigation.

Requirements:

Req. O32:

The FCF shall provide to each investigator on-line access to all digitized science data for at least 90 days following completion of on-orbit operations. The FCF shall identify and fill (as possible) all data gaps due to communication outages or equipment failures. The FCF shall verify formats, time codes, and any unit conversions included within the raw data set.

Req. O33:

The FCF shall identify availability of ancillary data

(accelerometry, Space Station attitude records, facility housekeeping data, etc.) that may be pertinent to each experiment as required in the Science Requirements Document. The FCF shall coordinate distribution and/or acquisition of data requested by each PI.

Req. O34:

The FCF shall identify one preferred medium and appropriate data format(s) for delivery of hard copies of all digitized science data for PI analysis and for archival. Recommended approach should be compatible with standard commercial practice and accessible commercial hardware and software configurations. Data shall be delivered within 60 days following completion of on-orbit operations.

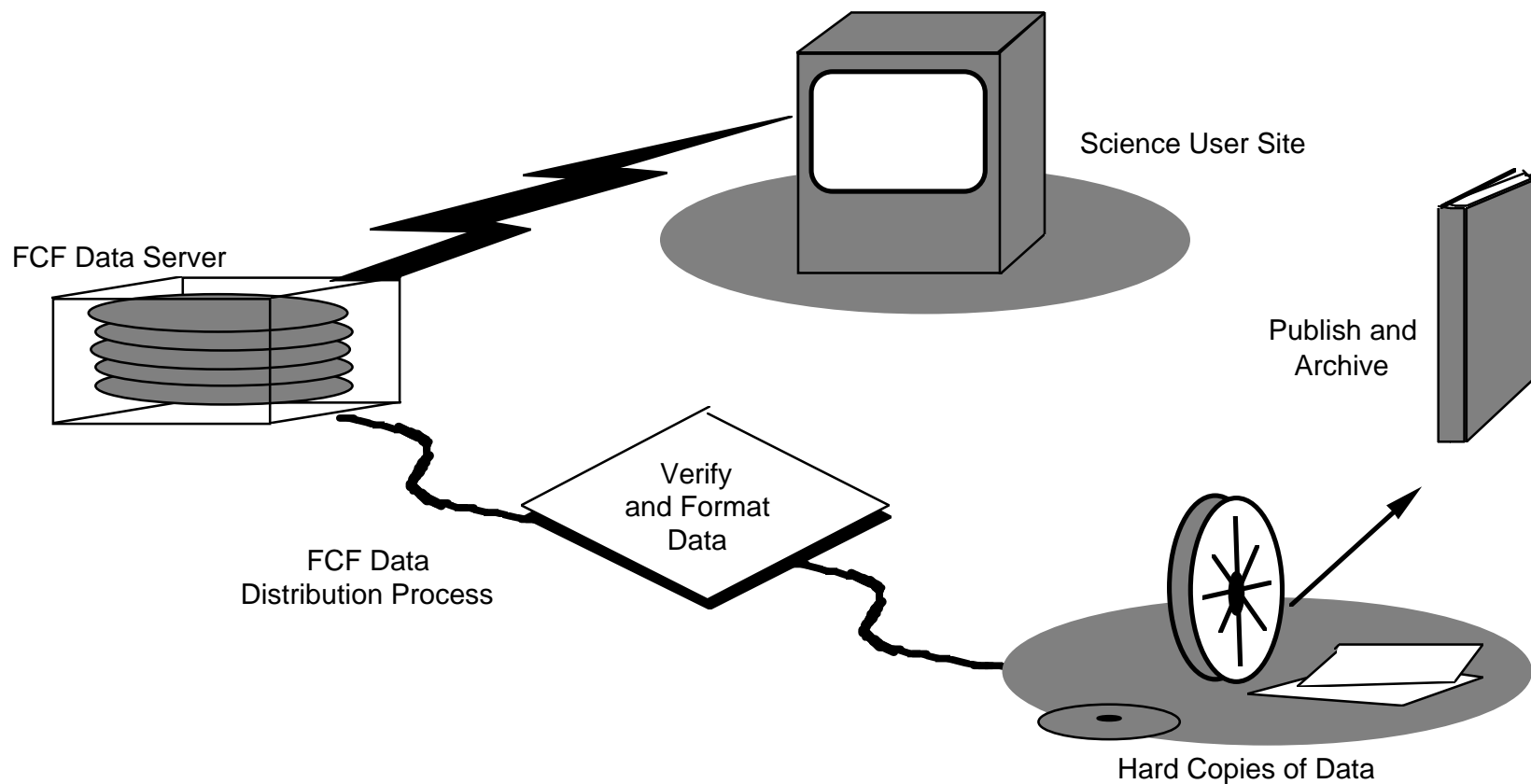
Req. O35:

The FCF shall provide an annual report for general distribution of nominal average environmental conditions (temperatures, accelerations, vibrations, et al.) during each experiment with time stamped record of deviations of likely significance to the investigator. The information in this report would be used to plan future experiments.

Facing figure displays principal elements and interfaces involved in data distribution.



POST FLIGHT DATA REDUCTION/DISTRIBUTION



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